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Plasma density role on instability growth of transverse-longitudinal coupled electromagnetic modes in the collisional dense plasma

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HIGHLIGHTS

- The body stress flow can be detrimental to the growth of transverse-longitudinal coupled electromagnetic modes.
- The collision effect on the growth of the electromagnetic mode is investigated.
- The kinetic Vlasov-Maxwell model has been used.
- Increasing the collision correction will lead to a reduction in the instability growth rate of the electromagnetic modes.

ABSTRACT

In this paper, the growth of transverse-longitudinal coupled electromagnetic modes in the interaction of high-intensity lasers with dense plasma investigated. Using kinetic theory and solving the scattering relationship for the Vlasov-Maxwell system, the collision effects on the growth of the electromagnetic mode are studied. The anisotropic distribution function considers the effects of body stress due to laser ponderomotive force and plasma density gradient. The results show that a 99% reduction in frequency in the beam path in dense plasma leads to an 88% increase in unstable modes' growth rate. Increasing the density prevents immediate cessation and enhances the growth of unstable modes. Increasing the density gradient by 99%, the instability rate maximum will increase by 88%. Overall, this paper provides insights into the effects of collision and anisotropic distribution function on the growth of transverse-longitudinal coupled electromagnetic modes in dense plasma. Overall, this paper provides insights into the interplay between various phenomena such as body stress, collision, and electromagnetic modes in dense plasma.

KEYWORDS
Body stress
Collision effects
Dense plasma
Density gradient
Electromagnetic modes

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1 Introduction

When a laser beam with an intensity of 10^{20} W.cm^{-2} and a very short pulse of around 10ps interacts with dense plasma, the plasma is heated primarily in the velocity dimension along the wave propagation direction. The ponderomotive pressure of laser-induced hot electrons drives the production and propagation of electron beams in an extremely unstable system. A few tens of mega bars of intense pressure are generated in the dense plasma. During the interaction, the plasma exerts a high pressure on the surrounding material, which leads to the formation of an intense shock wave. This shock wave carries the temperature anisotropy into the interior of the target (Liu and Chen, 2019; Khodadadi Azadboni, 2022; Bret and Dieckmann, 2020; Bret et al., 2005). When a beam propagates through plasma, it induces a return current to maintain current neutralization of the beam-plasma system (Jeet et al., 2021; Ali and Sarfraz, 2021; Hunana et al., 2019; Schoeffler and Silva, 2020). These currents produce a strong magnetic field of several megagauss around the beam, which amplifies the initial turbulence. As the pressure increases, the elements of the body are compressed. This compression cannot proceed freely in a continuum when the pressure is not uniform throughout, and thus, body stresses due to the flow of fluid are set up. The body flow alters the distribution function and leads to turbulence in plasma.

The body flow induced by the body stress can influence the nature of turbulence and associated transport. Such systems are unstable to any harmonic perturbations and produce electromagnetic modes that grow exponentially over time (Bendib et al., 1997; Khodadadi Azadboni and Mahdavi, 2017; Treumann and Baumjohann, 1997; Azadboni, 2021; Gremillet et al., 2007; Amininasab et al., 2018). An asymmetrical angular distribution function about the

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x-axis with a positive second anisotropic distribution function $T_x > T_\perp$ drives unstable $k_\perp$ modes. While a negative second anisotropic distribution function $T_x < T_\perp$ drives unstable k_x modes and leading to the generation of electromagnetic waves that propagate along the magnetic field and restore isotropy in phase space. The growth of transverse-longitudinal coupled electromagnetic modes in collisional dense plasma can be affected by body stress. Body stress refers to the stress that a material experiences due to an applied force or load. In the case of dense plasma, body stress can arise from a variety of sources, such as thermal or mechanical effects. The effect of body stress on the growth of these modes is complex and depends on the specific characteristics of the plasma and the nature of the stress (Amininasab et al., 2019; Abe and Niu, 1980b; Khodadadi Azadboni, 2021; Bret et al., 2004; Davidson et al., 2022). However, in general, body stress can lead to changes in the plasma density and temperature, which in turn can affect the propagation of electromagnetic waves. The investigation of instability resulting from electromagnetic modes in the interaction of high-intensity lasers with condensed plasma targets is an interesting topic of recent research (Krishnamurthy et al., 2020; Garasev et al., 2022; Hinton, 1983; Azadboni, 2024; Huynh et al., 2022; Dieckmann et al., 2020; Ghizzo et al., 2017). Body stress flow can affect convective flow in heat losses, increasing temperature anisotropy (Abe and Niu, 1980a). Temperature anisotropy plays a key role in energy transportation and can induce a large anomalous resistivity due to the privileged direction of the stress flow. The effect of Coulomb collision is an important mechanism for the absorption of high-frequency electromagnetic radiation by fully ionized plasma, which has been studied theoretically and experimentally. The presence of stresses caused by laser ponderomotive force has a significant role in the macroscopic behavior of plasma and can affect the nature of the disorder and its transmission.

The interaction between a beam and plasma is a complex process that involves various phenomena such as return currents, magnetic fields, body stresses, and turbulence. Understanding the interplay between these phenomena is an active area of research, particularly about the growth of transverse-longitudinal coupled electromagnetic modes in collisional dense plasma. While the effect of Coulomb collisions on the propagation of electromagnetic waves in turbulent plasma has been studied in previous works, such as (Abe and Niu, 1980b), the current study explores the specific influence of body stresses on the instability growth of these coupled modes in a collisional dense plasma environment. The collision frequency in turbulent plasma differs from that of the Maxwellian distribution, and this subject has not been considered before in this work. Based on plasma kinetic theory, this paper investigates the instability resulting from longitudinal-transverse coupled electromagnetic modes in collisional plasma in the presence of body stresses.

2 Theoretical model

Consider the dense plasma with the electron density 10^{21} cm^{-3}, which varies along the x-axis. The plasma heats up only in the direction of the electron wave propagation, which leads to a variable temperature anisotropy with the direction of the wave. The behavior of the unstable modes of the electromagnetic perturbations propagating along the plasma density gradient is evaluated by Maxwell's equations and Vlasov equation. To investigate the effect of Coulomb electron-ion collision on the propagation of electromagnetic modes, the collision sentence in the kinetic equation is considered. The linearized Boltzmann equation used to derive the dispersion linear as,

$$\frac{\partial f}{\partial t} + \vec{v}\frac{\partial f}{\partial \vec{r}} + \frac{q}{m_e}(\vec{E} + \frac{\vec{v}}{c} \times \vec{B})\frac{\partial f}{\partial \vec{v}} = -\nu(f - f_0). \quad (1)$$

The electron distribution function is defined as $f = f_0 + f_1$, where f_0 is the equilibrium distribution, and f_1 is the first-order perturbation of the distribution function. The expression for the collision frequency is denoted by ν. The distribution functions in the presence of the body stress and the temperature anisotropy deformed from the Maxwellian distribution. Therefore, anisotropy of the distribution function is defined as (Amininasab et al., 2019):

$$f_0(v) = \frac{1}{(\sqrt{2\pi}v_T)^3}[\sqrt{\eta} + P_{xx}\frac{\eta v_x v_y}{v_T^2}]\exp(-\frac{\eta v_x^2 + v_y^2}{2v_T^2}), \quad (2)$$

where $v_T = \sqrt{T_\perp^{2/3}T_\parallel^{1/3}/m_e}$ is thermal velocity, $T_\perp$ transverse temperature, $T_\parallel$ longitudinal temperature and $\eta(x,t) = (n_0/n_e(x,t))$ is the plasma density gradient. The temperatures in the perpendicular and parallel direction to the wave propagation are given as,

$$T_\perp = \frac{m_e}{2k_B}\int(v_\perp - \bar{v_\perp})^2 f(v)\mathrm{d}v,$$
$$T_\parallel = \frac{m_e}{2k_B}\int(v_\parallel - \bar{v_\parallel})^2 f(v)\mathrm{d}v, \quad (3)$$

where m_e is the electron mass, k_B is the Boltzmann constant, $v_\perp$ and $v_\parallel$ are the components of the electron velocity perpendicular and parallel to the wave propagation direction, respectively. $\bar{v_\perp}$ and $\bar{v_\parallel}$ are the corresponding mean velocities of the distribution function. These temperatures are used to define the temperature anisotropy of the electron distribution function. The initial electron density is $n_0 = 10^{21}$ cm^{-3}, and the electron density varies from $n_e(x,t) = 10^{21}$ to 10^{24} cm^{-3} along the x-axis. The density gradient η varies from 1 to 0.001, and the temperature is 20 keV with a temperature anisotropy $\beta = T_\parallel/T_\perp = 100$. The laser wavelength is 1 μm. The wave vector k is along the x-axis, the electric field E is along the y-axis, and the magnetic field B is along the z-axis. The perturbed electromagnetic fields and the perturbation current density are defined as,

$$\vec{\nabla} \times \vec{B_1} = \frac{4\pi}{c}\vec{J_1} + \frac{1}{c}\frac{\partial \vec{E_1}}{\partial t},$$
$$\vec{\nabla} \times \vec{E_1} = -\frac{1}{c}\frac{\partial \vec{B_1}}{\partial t}, \quad (4)$$
$$J_1 = n_e q\int v f_1 \mathrm{d}v.$$

The body stress is defined as

$$p_{xx} = n_e m_e\int(v_x^2 - v^2/3)f(v)\mathrm{d}v \quad (5)$$

The body stress tensor is a second-order moment of the electron distribution function and is defined as

$$\sigma_{ij} = \int (v_i - \bar{v_j})(v_j - \bar{v_j}) f(v) \mathrm{d}v, \tag{6}$$

where v_i and v_j are the i^{th} and j^{th} components of the electron velocity, respectively. The body stress tensor describes the internal forces within the plasma due to the pressure gradient. It is related to the temperature anisotropy and the plasma density gradient. In this position considered a rotation of the electron distribution function in the $x-y$ plane through an angle θ with density gradient η around the z-axis. To investigate the dependence of the scattering relation on the direction of the wave vector, the electron distribution function under the rotational angle θ defined by (Gremillet et al., 2007; Amininasab et al., 2018):

$$\begin{aligned} f_0(v) = \frac{\sqrt{\eta}}{(\sqrt{2\pi}v_T)^3}[1 + \frac{P_{xx}}{v_T^2}(\sqrt{\eta}v_x v_y \cos 2\theta \\ + \frac{\eta}{2}v_x^2 \sin 2\theta - \frac{1}{2}v_y^2 \sin 2\theta)]\exp(-\frac{\eta v_x^2 + v_y^2}{2v_T^2}). \end{aligned} \tag{7}$$

The collision frequency in turbulent plasma differs from that of Maxwellian distribution and is dependent on the value of stress and it can then be written as

$$\nu = -\frac{1}{m_e v_d n_e}\frac{\mathrm{d}p}{\mathrm{d}t} \tag{8}$$

where $v_d = \dfrac{\eta J}{n_0 e}$ is the drift velocity and p is the particle momentum per unit volume. The total rate of loss of momentum per unit volume is given by

$$\begin{aligned} \frac{\mathrm{d}p}{\mathrm{d}t} &= -\int_0^\infty \nu_p m_e \mathbf{v} f_0(\mathbf{v}) \mathrm{d}^3\mathbf{v} \\ &= \frac{2\pi n_e}{3}[1 + P_{xx}(\frac{\eta}{2}v_d \sin 2\theta)]\nu_p m_e v_d \eta. \end{aligned} \tag{9}$$

where collision frequency ν_p is defined as

$$\nu_p = \frac{Ze^4 n_i (m_e + m_i)}{\epsilon_0^2 m_i m_e^2 v_T^3} \ln \Lambda. \tag{10}$$

Here, Z is the ionic charge, and the expression $\ln \Lambda$ is the Coulomb logarithm. Substituting the distribution function and carrying out the integral of the Eq. (9), the collision frequency can then be written as

$$\nu = \frac{2\pi\eta}{3}\frac{Ze^4 n_i}{\epsilon_0^2 m_e^{1/2} T_\perp T_\parallel^{1/2}}[1 + P_{xx}(\frac{\eta}{2}v_d \sin 2\theta)] \ln \Lambda. \tag{11}$$

The collision frequency for quasi-Maxwellian distributed particles is larger than that of the Maxwellian, so the collision frequency increases with the body stress. After combining Maxwell's equations and applying a Fourier-Laplace transform, the dispersion relation for the transverse-longitudinal coupled electromagnetic modes is defined by:

$$\left| \varepsilon_{\alpha\beta}(\vec{k}, \omega) + (\frac{k_\alpha k_\beta}{k^2} - \delta_{\alpha\beta})(\frac{kc}{\omega})^2 \right| = 0. \tag{12}$$

where $\delta_{\alpha\beta}$ is the Kronecker delta, k is the wave vector, and $\varepsilon_{\alpha\beta}$ is a dielectric tensor takes the form:

$$\varepsilon_{\alpha\beta} = \delta_{\alpha\beta} + \frac{\omega_{pe}^2}{\omega\omega'}\int v_\alpha(\delta_{x\beta} + \frac{k_x v_\beta}{\omega - k_x v_x})\frac{\partial f_0}{\partial v_x}\mathrm{d}\vec{v}, \tag{13}$$

where $\omega' = \omega + i\nu$. The imaginary positive part of the frequency is the electromagnetic instability. The dielectric tensor $\varepsilon_{\alpha\beta}$ considers the plasma's effects on electromagnetic wave propagation. The dispersion relation relates the frequency and wave vector of the electromagnetic wave to the properties of the plasma. The dielectric tensor depends on the properties of the plasma, such as the electron density, electron temperature, and magnetic field strength. It describes how the plasma affects the propagation of electromagnetic waves, including dispersion and absorption. The dielectric tensor is a complex tensor, and its real and imaginary parts describe the plasma's refractive index and absorption coefficient, respectively. The plasma frequency is a fundamental parameter that characterizes the behavior of a plasma. It is defined as the natural frequency of oscillation of the charged particles in the plasma, and it depends on the electron density

$$\omega_{pe} = \sqrt{\frac{4\pi e^2 n_0}{\eta m_e}} \tag{14}$$

where e is the elementary charge, and m_e is the electron mass. The plasma frequency measures the strength of the collective motion of the charged particles in the plasma. The plasma frequency determines the cutoff frequency for electromagnetic waves in the plasma, below which the waves cannot propagate due to the strong interaction with the charged particles. The plasma frequency is an important parameter in plasma physics and describes a wide range of phenomena, including wave propagation, instabilities, and heating. By placing the distribution function in the scattering relation, the components of the dielectric tensor are:

$$\begin{aligned} \varepsilon_{xx} =& 1 - \frac{\omega_{pe}^2}{\omega\omega'}\Big\{ -\eta\sqrt{\eta}\zeta^2 Z(\zeta) \\ &+ \frac{\eta\sqrt{\eta}}{4}P_{xx}(2 - 3\sin^2\theta) \\ &\times [-\frac{\zeta^2}{\sqrt{\eta}} + Z(\zeta)\zeta^2(3 - \eta\zeta^2)]\Big\}, \end{aligned} \tag{15}$$

$$\begin{aligned} \varepsilon_{zz} =& 1 - \frac{\omega_{pe}^2}{\omega\omega'}\Big\{1 - \eta\sqrt{\eta}Z(\zeta) \\ &+ \frac{\eta\sqrt{\eta}}{4}P_{xx}[\frac{1}{\sqrt{\eta}}(2 - 3\sin^2\theta) \\ &+ Z(\zeta)(8 - 9\sin^2\theta - \eta\zeta^2(2 - 3\sin^2\theta))]\Big\}, \end{aligned} \tag{16}$$

$$\begin{aligned} \varepsilon_{yy} =& 1 - \frac{\omega_{pe}^2}{\omega\omega'}\Big\{1 - \eta\sqrt{\eta}Z(\zeta) \\ &+ \frac{\eta\sqrt{\eta}}{4}P_{xx}[\frac{1}{\sqrt{\eta}}(2 - 3\sin^2\theta) \\ &+ Z(\zeta)(8 - 15\sin^2\theta - \eta\zeta^2(2 - 3\sin^2\theta))]\Big\}, \end{aligned} \tag{17}$$

$$\varepsilon_{xy} = \varepsilon_{yx} = \frac{\omega_{pe}^2}{\omega\omega'}\frac{3\eta}{4}P_{xx}\sin 2\theta \times [\frac{1}{\sqrt{\eta}} - Z(\zeta)(1-\eta\zeta^2)]. \quad (18)$$

where $\zeta = (\omega + i\nu)/kv_T$ is the phase velocity normalized by thermal velocity. Due to the symmetry of the distribution function, the ε_{xz} and ε_{yz} components become zeros. The plasma dispersion function defined as follows:

$$Z(\zeta) = \frac{\eta}{2\sqrt{2\pi}}\int_{-\infty}^{+\infty} -t^2\exp(\frac{t}{t-\zeta})\mathrm{d}t. \quad (19)$$

The plasma dispersion function is a complex function of the complex variable ζ, and it has both real and imaginary parts. It plays an important role in the analysis of wave propagation and stability in plasmas, particularly for collisionless plasmas. The real part of the plasma dispersion function determines the phase velocity of the wave, while the imaginary part determines the wave damping or growth rate. The plasma dispersion function can be evaluated numerically or using analytical approximations for specific regimes of ζ. The dispersion relation for the transverse-longitudinal coupled electromagnetic modes in a plasma can be written as:

$$\varepsilon_{xy}^2 - \varepsilon_{xx}\varepsilon_{yy} + \varepsilon_{xx}(\frac{kc}{\omega})^2 = 0. \quad (20)$$

The dispersion relation is solved by putting the plasma dispersion function in equations of the dielectric tensor components, and cede second order and higher of ζ. This dispersion relation describes the interaction between the electromagnetic wave and the plasma, and it determines the propagation and stability properties of the wave. The instability growth rate for the transverse-longitudinal coupled mode is given as

$$\delta = -kv_T[(1-\eta) + 3\eta p_{xx}(\frac{1}{2} + \sin^2\theta) + (\frac{kc}{\omega})^2 + \frac{\pi}{2}\frac{\eta^2(\frac{3p_{xx}}{4})^2\sin^2 2\theta}{1-\frac{p_{xx}}{2}(2-3\sin^2\theta)}] - \nu\chi/\psi, \quad (21)$$

where

$$\chi = \eta\sqrt{\frac{\pi\eta}{2}}(1 + 2p_{xx} - 15\frac{p_{xx}}{4}\sin^2 2\theta) + 4\eta\sqrt{\frac{\pi\eta}{2}}\frac{(\frac{3p_{xx}}{4})^2\sin^2 2\theta}{1-\frac{p_{xx}}{2}(2-3\sin^2\theta)}, \quad (22)$$

and

$$\psi = \eta\sqrt{\frac{\pi\eta}{2}}(1 - \frac{p_{xx}}{4}(8 - 15\sin^2\theta)) + \frac{1}{\eta}\frac{(\frac{3p_{xx}}{4})^2\sin^2 2\theta}{1-\frac{p_{xx}}{2}(2-3\sin^2\theta)} \times [4 - \frac{\pi}{2}\frac{1-\frac{p_{xx}}{4}(2-3\sin^2\theta)}{1-\frac{p_{xx}}{2}(2-3\sin^2\theta)}]. \quad (23)$$

Instability may grow in different directions of wave propagation, and the largest growth rate is related to the wave perpendicular to the higher temperature. Without body stress, $p_{xx} = 0$, the growth rate of instability is simplified as follows:

$$\delta_{P_{xx}=0} = -kv_T[(\frac{kc}{\omega_p})^2 + 1 - \eta] - \nu. \quad (24)$$

The transverse-longitudinal coupled modes provide instability when $\delta > 0$. Therefore, the instability will grow if

$$kv_T\Big[(1-\eta) + 3\eta p_{xx}(\frac{1}{2} + \sin^2\theta) + (\frac{kc}{\omega})^2 + \frac{\pi}{2}\frac{\eta^2(\frac{3p_{xx}}{4})^2\sin^2 2\theta}{1-\frac{p_{xx}}{2}(2-3\sin^2\theta)}\Big] + \nu\chi < 0 \quad (25)$$

The transverse-longitudinal coupled mode is damping when the threshold value for the body stress tensor is not exceeded, which corresponds to $\delta_{p_{xx}} < 0$. In this case, the equilibrium distribution function is stable. However, if p_{xx} is large enough to exceed the threshold value, $\delta_{p_{xx}}$ becomes positive, and the transverse-longitudinal coupled mode becomes unstable. This means that there will be an incremental deformation of the distribution function from equilibrium due to the body stress, which gives rise to instability. The instability growth rate depends on the wave vector, electron density, and temperature anisotropy, as well as the magnitude of the body stress tensor.

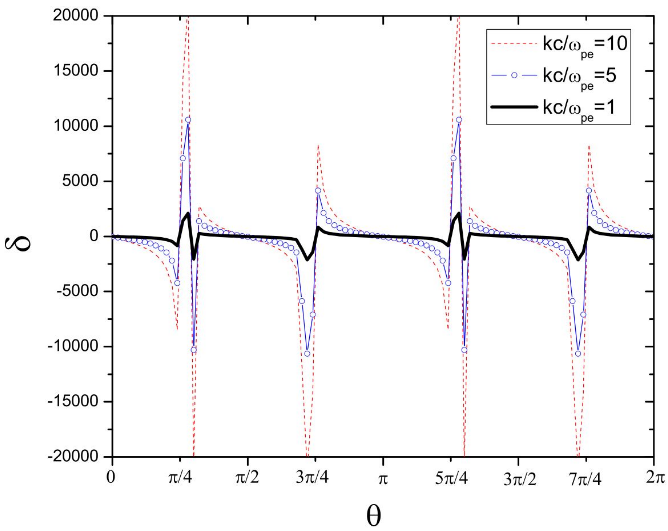

Figure 1: Variation of the growth rate of the instability of transverse-longitudinal coupled electromagnetic modes, δ, as a function of the rotation angle θ for the number of different normalized waves kc/ω_{pe}

3 Results and Discussion

The paper investigates the behavior of unstable modes of the electromagnetic perturbations propagating along the plasma density gradient in dense plasma with a varying electron density along the x-axis. The instability growth variation of longitudinally-transverse electromagnetic modes in the corona of plasma as a function of rotation angle for different wave numbers are shown in Fig. 1. As shown in Fig. 1, in the plasma corona that $\eta = 1$

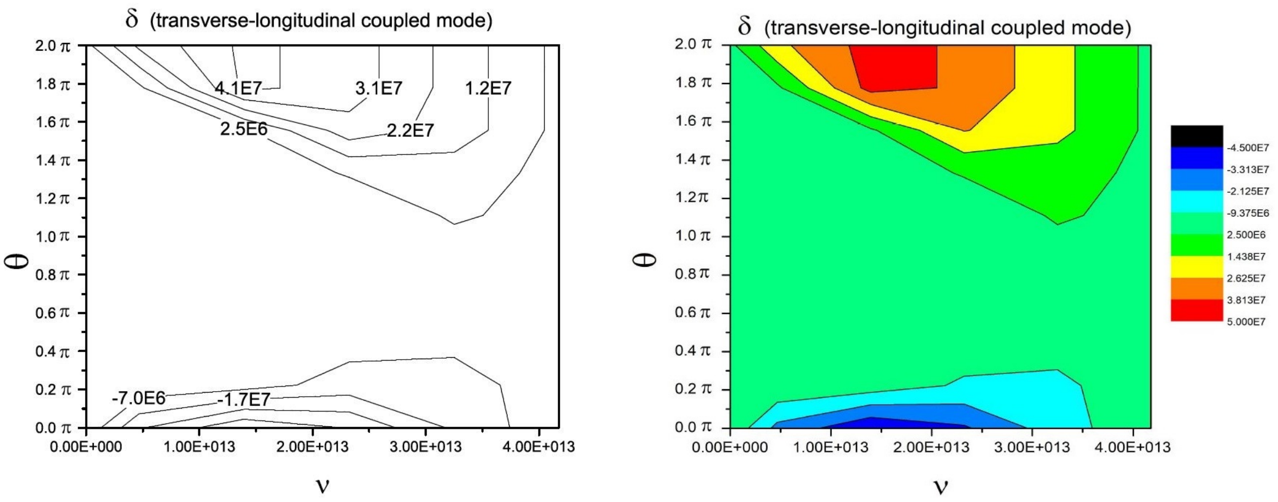

Figure 2: Variation of the instability growth rate of longitudinal-transverse coupled electromagnetic modes, δ, in the collision frequency plane ν and the propagation angle of electromagnetic modes θ for the waves number $kc/\omega_{pe} = 10$ and the density gradient $\eta = 0.01$.

the maximum instability growth rate of electromagnetic modes $\delta > 0$ will occur around the propagation angles $\theta = \pi/4$ and $\theta = 5\pi/4$. The maximum growth rate of instability increases with increasing wave number. The maximum value of the instability growth of the transverse-longitudinal coupled mode in $\theta = 0.28\pi$ can be varied from 1864 to 21421 by varying the value of kc/ω_{pe} from 1 to 10. As the wave number increases 10 times, the maximum instability growth rate will increase 9.3 times. Contours of the electromagnetic modes propagation versus variation the collision frequency in $\eta = 0.01$ is shown in Fig. 2. A comparison of figure 1 and figure 2 concludes that the maximum instability will increase with decreasing density gradient, η. The collisions effect on the instability growth rate is investigated. For $10^{13} < \nu < 2 \times 10^{13}$, increasing the beam oscillating energy around the diffusion angles $\theta = 1.8\pi - 2\pi$ will increase the instability growth. The electron during contact with the ion population and temperature expansion loses some of its energy which reduces the instability growth rate. In a collisional plasma, the collisions between particles can cause the electron distribution function to deviate from the Maxwellian distribution, and this can lead to a reduction in the instability growth rate for the transverse-longitudinal coupled mode. As the collision frequency increases, the electron population has more opportunities to interact with the ion population and thermalize, which reduces the deviation from Maxwellian and hence the instability growth rate. The figure shows that the instability growth rate decreases with an increase in the collision frequency, and for collision frequencies above 310^{13} Hz, even a slight increase in the collision frequency can lead to a significant reduction in the growth rate of the instability of the electromagnetic modes. This implies that collisions play an important role in determining the stability properties of a plasma, particularly for high-collisionality plasmas.

4 Conclusions

The interaction between a laser beam and dense plasma involves various phenomena such as the generation of return currents, magnetic fields, body stresses, and turbulence. The growth of transverse-longitudinal coupled electromagnetic modes in collisional dense plasma can be affected by body stress, which can lead to changes in plasma density and temperature that affect the propagation of electromagnetic waves. Understanding the interplay between these phenomena is an active area of research. In this paper, the instability resulting from longitudinal-transverse coupled electromagnetic modes in collisional plasma in the presence of body stresses is investigated based on plasma kinetic theory. The dynamics of electrons are described by the linearized Boltzmann equation, and in the presence of body stress, the dispersion relation for transverse-longitudinal coupled modes in a turbulent system is obtained with an anisotropic quasi-Maxwellian distribution function. The calculations show that increasing density gradient widens the propagation angle of electromagnetic modes, while decreasing wave number increases the range of propagation angles of the growing electromagnetic modes. A decrease of 100 times in wave number leads to an 88% increase in the growth rate maximum of the electromagnetic longitudinal-transverse coupled modes. As the density gradient increases and wave number decreases in the electron beam path, the growth rate of instability due to the coupling of the side bands increases with the oscillation rate of the electron. The threshold of body stress for instability becomes minimum when the wave vector is along the specified direction of electromagnetic mode emissions. Increasing collision correction leads to a significant reduction in the instability growth rate of longitudinally-transverse coupled electromagnetic modes. Overall, this paper provides insights into the effects of collision in dense plasma on the growth rate of electromagnetic longitudinal-transverse coupled modes and their interplay with body stress.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work.

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